

The Nucleon Cluster Model and Thermal Neutron Fission

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Editor's Note: *Infinite Energy* has previously covered the multi-decade work of Ronald Brightsen and his Nucleon Cluster Model (NCM), which originated in the late 1940s:

Brightsen, R.A. 1995. "Application of the Nucleon Cluster Model to Experimental Results," *Infinite Energy*, 1, 3, 13.

Brightsen, R.A. 1995. "Nucleon Cluster Structures in Beta-Stable Nuclides," *Infinite Energy*, 1, 4, 55.

Brightsen, R.A. 1995/96. "Correspondence of the Nucleon Cluster Model with the Periodic Table of Elements," *Infinite Energy*, 1, 5/6, 73.

Bass, Robert W. 1996. "Experimental Evidence Favoring Brightsen's Nucleon Cluster Model," *Infinite Energy*, 2, 11, 78.

Brightsen's basic concept is that nuclei are composed of three kinds of nucleon clusters—NPN, PNP, and NP (where N is a neutron and P is a proton; note that the ordinary hydrogen nucleus, P, is a very special case, according to Brightsen!).

One may wonder why we are now publishing a paper by Brightsen which was written in late 1989 and put in revised form in March 1992. This paper deals primarily with explaining patterns in conventional thermal neutron fission. Brightsen attempts to show the NCM's application to what one might have thought was a topic on which "the book had been closed." As Brightsen states: "An immense

amount of experimental data has been accumulated on nuclear fission, certainly one of the most complex nuclear reactions observed in nuclear physics. Despite the data accumulation, a comprehensive theory or model which accounts for all the known data has not yet been developed."

The advent of low-energy nuclear transmutation phenomena, which has been observed in electrochemical systems by researchers such as Professor George Miley at the University of Illinois, and Doctors Mizuno and Ohmori at Hokkaido University, makes new models of nuclear structure of great interest. After all, these researchers appear to be seeing characteristic "cold fission" fragment distributions in their data. Could it be that Brightsen's Nucleon Cluster Model has some explanatory value in such experiments, as it appears to have for thermal neutron fission? We hope that the long-delayed publication of this paper will prompt some more mathematically inclined investigators to determine, once and for all, whether Brightsen's model of thermal neutron fission is "just" some kind of curve-fitting, or whether it perhaps has some deeper significance for nuclear theory and perhaps, as Brightsen believes, to cold fusion and new energy.—EFM

Abstract

Utilizing a new Nucleon Cluster Model (NCM) of the nucleus, the overall nature of which is summarized herein, the process of thermal neutron fission is described. Known experimental results are explained and quantified. Using the NCM, fission yield curves, the average number of prompt neutrons per fission ($\bar{\nu}$) and the emission of light charged particles (LCP) are all derived. The quantitative relationships presented provide an excellent fit to well-known data and systematically describe a framework for the fission process. The NCM suggests that fission takes place in four modes. This paper describes the light and heavy fragments for each fission mode, as well as their unique and systematic prompt neutron and light charged particle yields. Well-established experimental results for thermal neutron fission of U-235, as well as U-233, Pu-239, and Pu-241, are accurately reproduced for the first time since fission was discovered in 1939. These results provide support for the validity of the NCM.

Introduction

Thermal neutron fission of U-235, discovered in 1939 by Hahn and Strassman,¹ has been investigated intensively by physicists worldwide for five decades. An immense amount of experimental data has been accumulated on nuclear fission, certainly one of the most complex nuclear reactions observed in nuclear physics. Despite the data accumulation, a comprehensive theory or model which

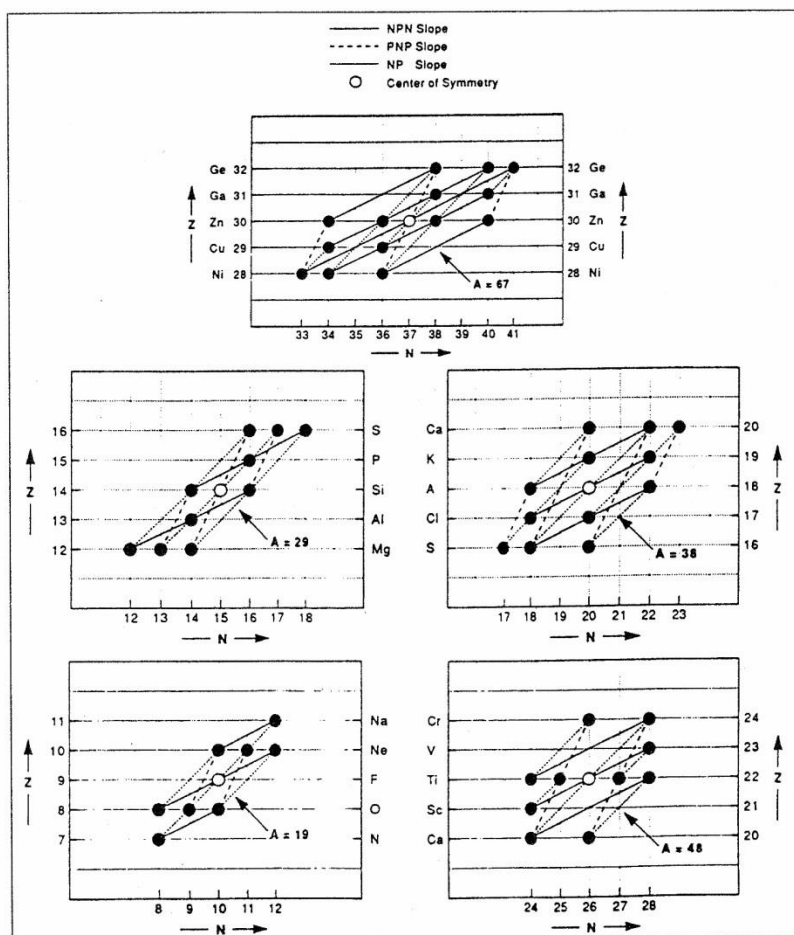


Figure 1. Mass-Charge Symmetry Systems. ○ ● Beta stable nuclides

accounts for all the known data has not yet been developed.

The research reported in this paper provides deterministic answers to four of the major unresolved questions regarding thermal neutron fission by utilizing the Nucleon Cluster Model (NCM), which is a new concept in nuclear clustering.² Specifically, these four questions are:

- 1) What accounts for the asymmetric mass distribution³ of the fission fragments in thermal neutron fission of U-233, U-235, Pu-239, and Pu-241?
- 2) What is the origin of the prompt neutrons that produce, in the aggregate, the experimentally observed average number of neutrons per fission ($\bar{\nu}$)?
- 3) What mass splits account for the variation in $\bar{\nu}$ from zero in some mass splits to as many as six in others?
- 4) What is the origin of the many light charged particles (especially He-4 and H-3) observed in fission?

Nucleon Cluster Model (NCM) and Nuclear Fission

The NCM resulted from a long and persistent search for beta-stability selection rules that would be applicable across the

entire mass range. In 1983 that research uncovered systematics that are valid from the lightest to the heaviest nuclides. The key was the discovery that all nuclides can be described by *three* nucleon clusters (NPN, PNP, and NP). Such cluster structures are in striking contrast with conventional nuclear physics, which describes all nuclides with only two parameters, N and Z (where $Z \equiv P$). Because of the revolutionary nature of this new nuclear model, it was decided to postpone publication until convincing evidence could be published in support of the NCM. Such evidence is presented in this paper. It explains, for the first time and in a remarkably accurate and deterministic manner, many of the observed experimental results of thermal neutron fission.

At the same time, it may be important to point out what the NCM does not yet explain. It does not deal with the "morphology" of the nuclides, *i.e.* it does not address the manner in which the clusters are arranged within each nucleus, nor does it deal with the shape or size of the clusters. We believe that these questions will ultimately be answered. At the present time, the NCM leads one to conclude that there are at least two significantly different binding energies involved in nuclear binding: the binding energies within and between the clusters.

A key observation leading to the development of the NCM was the recognition of heretofore unreported mass-charge symmetry systems among certain groups of beta-stable nuclides. Such symmetry becomes apparent in Z (proton) vs. N (neutron) plots, some of which are shown in Figure 1. It was immediately apparent that these centers of symmetry had a simple relationship among the mass numbers, *i.e.* $19 + 48 = 67$ and $29 + 38 = 67$, but no obvious relationship connecting the nuclear charge (Z) values. The three slopes (NPN, PNP, and NP) evident (see Figure 1) in these mass-charge symmetry systems imply that nuclei contain clusters consisting of NPN, PNP, and NP.

The probable connection of the NCM to fission was first noticed in two relationships: 1) $A = 67$ is very close to the beginning of the light "tail" in fission and 2) a pronounced fine structure peak in thermal neutron fission of U-235 occurs at $A = 134$ (2×67). Further research in the application of the NCM to the fission process resulted in the development of a "Periodic Table of Nuclides," a portion of which is shown in Figure 2. The horizontal scale of the independent variable A is folded into Periods of $\Delta A = 67$, and each Period is folded into two sub-groups. This latter folding, together with symmetry considerations, requires two junctions for each Period in the Periodic Table of Nuclides. In the fission fragment mass range shown in Figure 2, the following three junctions occur:

	Junction	Junction	Junction
$A_{\text{light}} \rightarrow A_{\text{heavy}}$	82 84 86	115 117 119	149 151 153
$A_{\text{heavy}} \rightarrow A_{\text{light}}$	86 84 82	119 117 115	153 151 149
Σ_A	168 168 168	234 234 234	302 302 302

The vertical scale of the dependent variable Σ_3 represents the number of triplet clusters (NPN plus PNP) in each mass number A plotted. The numbers in the circles represent the number of doublet clusters (NP) in each of the plotted A values, all along the sloping lines connecting squares that are inscribed with the mass numbers. The regular periodicity of $\Delta A = 67$ is evident in Figure 2. It should be noted that this periodicity continues for mass numbers lighter than, as well as heavier than, those found in fission.

The periodicity of $\Delta A = 67$ is an inherent property of the NCM. The significance of $\Delta A = 67$ may eventually be revealed when the mathematical/theoretical bases of the NCM is developed. Note the frequent occurrence of this number in Figure 3, derived from Figure 2.

There is a striking correspondence between the branches of

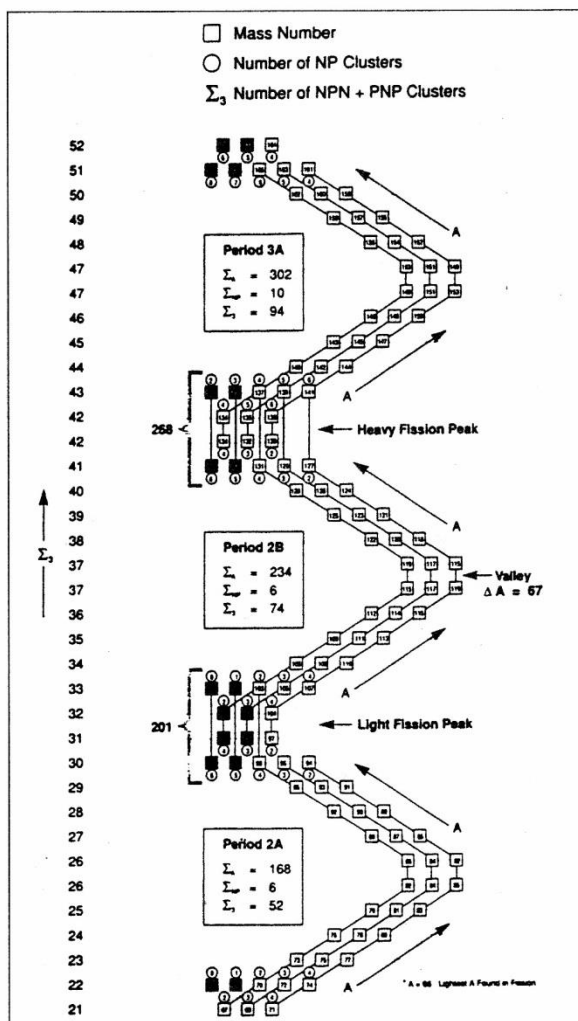


Figure 2. Periodic Table of Nuclides. Periods 2A, 2B, and 3A ($A = 66-169$). Figures are shown as provided by the author.

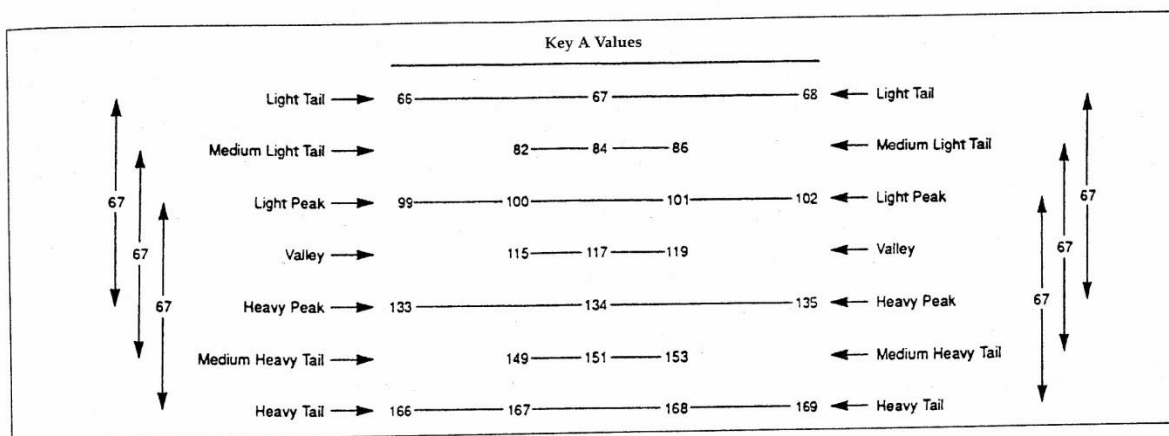


Figure 3. Thermal Neutron Fission of U-235. Fission-related Key A Values of the Nucleon Cluster Model.

the Periodic Table of Nuclides shown in Figure 2 and the five major features of fission yield curves for each of the four fissile nuclides (U-233, U-235, Pu-239, and Pu-241). The five features of those yield curves are: 1) light tail, 2) light peak, 3) valley, 4) heavy peak, and 5) heavy tail. This paper focuses principally on the correspondence between Figure 2 and one of the fissile nuclides, namely the experimental fission yield curve of U-235, shown in Figure 4. The correlation between those two systems, the NCM and an experimentally determined fission yield curve, applies to fission fragments ranging from $A = 66$ (known in fission) to $A = 169$ (not yet found in fission). An inspection of Figure 2 reveals the following:

- 1) The Junction in Period 2B corresponds to the "valley" in thermal neutron fission of U-235.
- 2) In thermal neutron fission of U-235, the junction of Period 2A and 2B corresponds to the "light peak," while the junction of Period 2B and 3A correlates with the "heavy peak," respectively.
- 3) Periods 2A and 3A represent the "tail" from the light peak and heavy peak, respectively.

The strong correlations between the characteristics of Figure 2 (summarized in Figure 3) and the experimental U-235 fission yield curve (Figure 4) precipitated a decision to conduct research on U-235 thermal neutron fission to test the validity of the NCM. This research has been supported in part by the Electric Power Research Institute.

The Four Thermal Neutron Fission Modes of U-235

It should be noted that when U-235 absorbs a thermal neutron, it becomes the fissioning compound nucleus, U-236. Fission occurs in four distinct modes, explained in further detail below, that are characterized by the type and number of particles emitted and by the mass range of the mode. Mode A releases one neutron, Mode B generates two neutrons, Mode C boils off six neutrons, and Mode D emits three neutrons as well as alpha particles and tritons.

The unique correspondence between the two systems—the Periodic Table of Nuclides and the experimental fission yield curve—is no coincidence.

Mode A: This fission mode is derived directly from the Periodic Table of Nuclides. Period 2A and 3A (Figure 2) sum to 235, suggesting that this mode systematically releases one neutron per fission. The light fragments of this mode extend from $A = 66$ (the lowest A value found in fission—excluding the very light charged

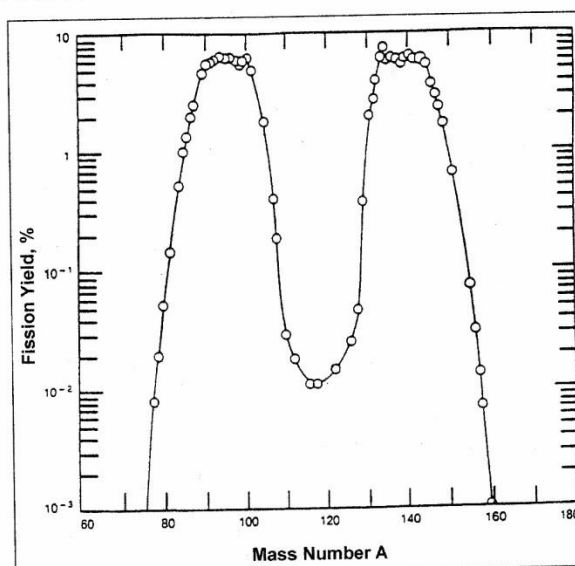


Figure 4. Thermal Neutron Fission of U-235.

particles) to $A = 102$, with corresponding initial heavy partners from $A = 170$ to $A = 134$. Each fission in Mode A emits one neutron, from the heavy fragment. This is consistent with experimental evidence, which indicates that more neutrons are produced by heavy fragments than by light fragments. Thus, subsequent to a single neutron emission from the heavy fragment, the mass of the light and heavy fragments sum to 235 as follows:

Light Fragment	66	102
Heavy Fragment	169	133
SUM	235	235

It should be noted that:

$A = 66$ is the beginning of the "light tail" in the fission yield curve, while $A = 169$ is the end of the "heavy tail." (See Figure 4.) $A = 102$ is part of the light peak and $A = 133$ part of the heavy peak in the fission yield curve. (See Figure 4.) $A = 66, 102, 133,$ and 169 are Key A values of the NCM. (See Figure 3.)

Mode B: This fission mode is also derived directly from the Periodic Table of Nuclides. The two sub-groups of Period 2B sum to 234 (Figure 2), suggesting a mode which systematically generates two neutrons per fission. The initial light fragments in Mode B begin at $A = 100$ and extend to $A = 120$, while the heavy initial fragments correspond to $A = 136$ through $A = 116$. Each fission in Mode B releases two neutrons, one from the heavy fragment and one from the light fragment. Thus, subsequent to neutron emission, the mass of the light and heavy fragments sum to 234 as follows:

Light Fragment	115	99
Heavy Fragment	<u>119</u>	<u>135</u>
SUM	234	234

It should be noted that:

$A = 115$ and 119 are at the approximate center of the "valley" in the fission yield curve. (See Figure 4.)

$A = 99$ and 135 are part of the light and heavy peaks in the fission yield curve. (See Figure 4.)

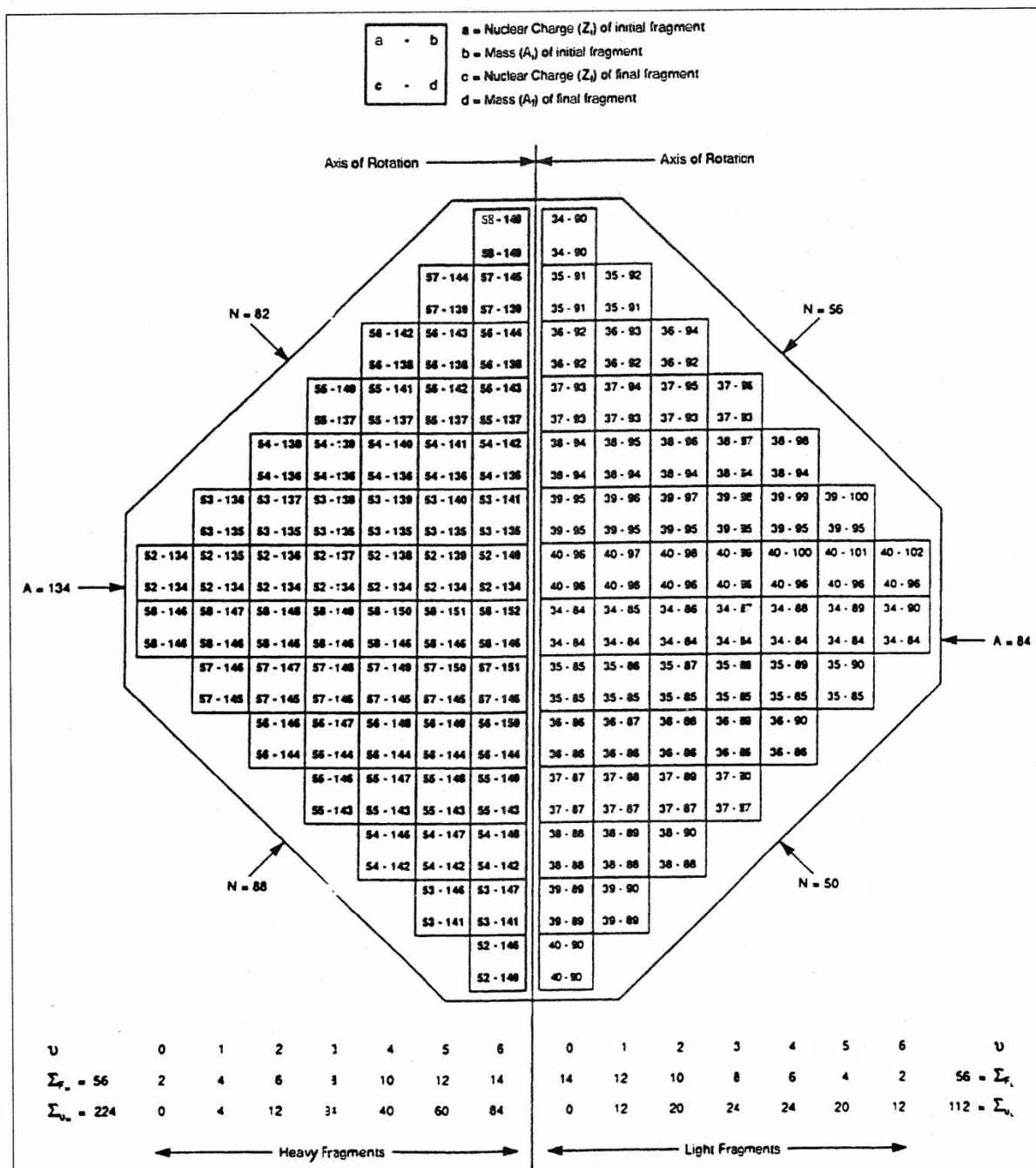


Figure 5. Thermal Neutron Fission of U-235. Fission Mode C.

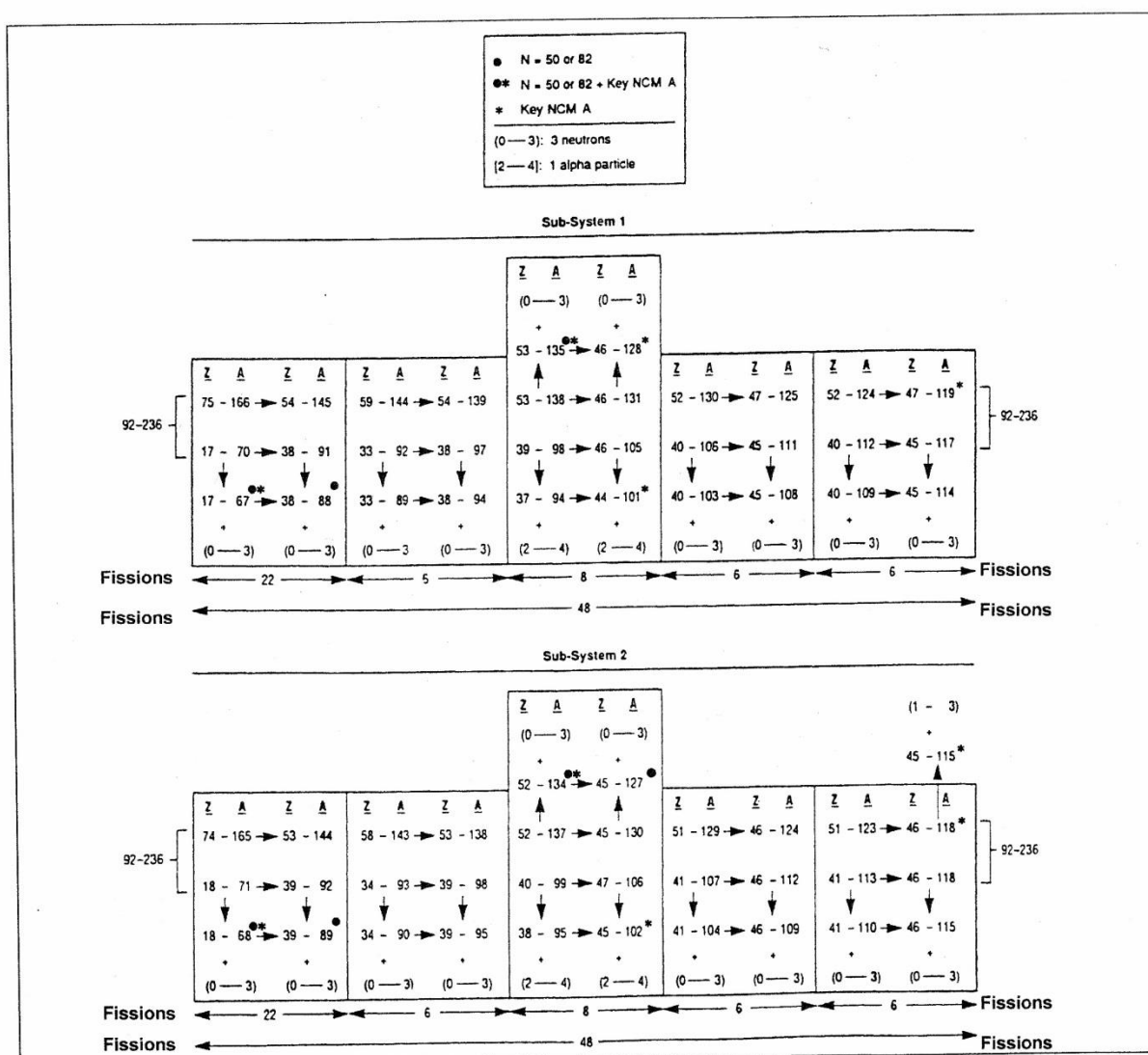
A = 99, 115, 119, and 135 are Key A values of the NCM. (See Figure 3.)

Clearly, no combination of Modes A and B could yield an experimentally known value of $2.416 \pm .008$ for $\bar{\nu}$, the average number of prompt neutrons per fission.⁴ Consequently, research was initiated using the NCM as a guide to develop one or more modes to:

- 1) explain the experimentally known fact that, in U-235 fission, ν has values of 0, 1, 2, 3, 4, 5, and 6 for various mass splits;
- 2) explain the influence of the "magic numbers,"⁵ $N = 50$ and $N = 82$;
- 3) explain the experimentally observed ratios of the light charged particles, especially the He-4 and H-3 ratio of 16.

Mode C: It has long been known that, in thermal neutron fission, the light side of the heavy peak fission yield is nearly a constant,⁶ and this persistent pattern has been attributed in part to the closed-neutron ($N = 82$) shell found in this mass region. This knowledge led to a postulate that systematic neutron emission might occur when the initial fragments contained 83, 84, 85, 86, 87,

and 88 neutrons, with no neutron emission when the initial fragment contained 82 neutrons. Such a model would certainly account for the experimentally observed variation of ν , while explaining the influence of $N = 82$. This "boil-off" model might also extend to $N = 50$. After considerable research, Fission Mode C was developed (Figure 5). This systematic but complex mode boils off six neutrons for each fission, with twice as many neutrons coming from heavy fragments as from light fragments. In this system, one fragment may release X neutrons (with X having values of 0 to 6) while the other fragment will release $6-X$. It should be noted that the final heavy fragments in the upper left quadrant all contain 82 neutrons, while their light fragment counterparts contain 56 neutrons. Similarly, the final light fragments in the lower right quadrant all contain 50 neutrons, while their heavy counterparts contain 88 neutrons. Finally, it should be noted that the postulated Mode C indicates that the initial light fragments commence at $A = 84$ and terminate at $A = 102$, while the initial heavy fragments commence at $A = 134$ and terminate at $A = 152$. These A values are all key NCM A values. (See Figure 3.)



Mode D: This mode was postulated and developed to account for the origin of alpha particles and tritons in fission. Two key experimental results had to be incorporated: 1) Alpha particles are observed in about one out of every 300 to 500 fissions. 2) The experimental ratio of alpha particles to tritons is extremely close to sixteen.

The model developed for Mode D consists of two sub-systems, each of which produces forty-eight fissions and three neutrons per fission. Each sub-system releases eight alpha particles, producing an alpha particle per fission ratio of 16/96 (.16667) for Mode D. In the unique case of completely symmetric fission, in which the mass and charge of both fragments are identical (46-118 + 46-118), one fragment emits three neutrons to become 46-115, while the other fragment emits a triton, to become 45-115. Fission Mode D is shown in Figure 6. In summary, Mode D not only emits three neutrons per fission, but also sixteen alpha particles and one triton. Thus, the NCM produces an alpha particle to triton ratio of sixteen, in excellent agreement with the experimental value⁷ of 15.9-16.1. Careful examination of Figure 6 will reveal that key NCM A values, as well as $N = 50$ and $N = 82$, play a significant role in Mode D.

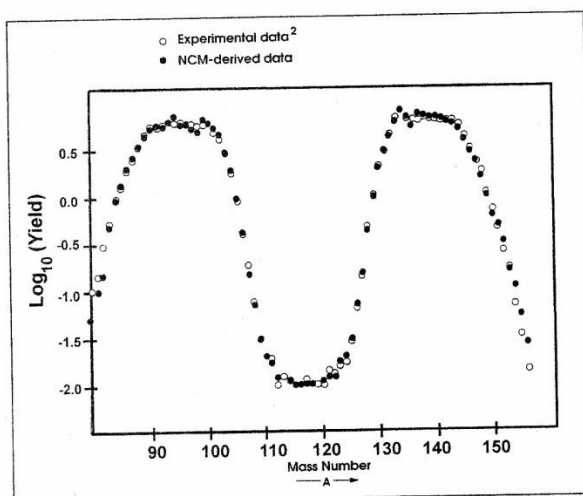


Figure 7. Fission Yields for Thermal Neutron Fission of U-235.

Fission Mode M	ν_M	f		f		f		f		f	
		f	$f \nu$	f	$f \nu$	f	$f \nu$	f	$f \nu$	f	$f \nu$
A	1	11	11	22	22	33	33	44	44	55	55
B	2	6	12	12	24	18	36	24	48	30	60
C	6	5	30	10	60	15	90	20	120	25	150
D	3	1	3	1	3	1	3	1	3	1	3
Sum		$\Sigma_f = 23$	$\Sigma_{f\nu} = 56$	$\Sigma_f = 45$	$\Sigma_{f\nu} = 109$	$\Sigma_f = 67$	$\Sigma_{f\nu} = 162$	$\Sigma_f = 89$	$\Sigma_{f\nu} = 215$	$\Sigma_f = 111$	$\Sigma_{f\nu} = 268$
$\bar{\nu} = \Sigma_{f\nu} / \Sigma_f =$		2.43478		2.42222		2.41791		2.41573		2.41441	
Acceptable*		No		Yes		Yes		Yes		Yes	

*Within limits of error for $\bar{\nu} = 2.416 \pm .008$.

Figure 8. Thermal Neutron Fission of U-235. Calculation of $\bar{\nu}$ for integral frequency sets within required frequency conditions.

Derivation of Fission Yield Curve for U-235, $\bar{\nu}$, and the Alpha Particle Yield

Using the final fragment mass ranges for each mode, neutron emissions from the four modes, and experimental fission yields,³ as well as a constraint that $\bar{\nu}$ be very close to 2.416, a preliminary fission yield curve was derived (Appendix A) and is shown in Figure 7. The yield percent attributable to each mode was calculated as follows:

Fission Mode	ν	Final Mass Range		Percent Yield	$\bar{\nu}$
		Light	Heavy		
A	1	66-102	133-169	49.73	.4973
B	2	99-115	119-135	27.40	.5480
C	6	84-96	134-146	22.83	1.3698
D	3	67-115	118-166	.04	.0012
TOTAL				100.00	2.4163

Since the percent yields for each fission mode can, of course, be expressed as integral frequencies, research was initiated to see whether the percent yield information shown above could be expressed as integral frequencies, resulting in:

- The correct value, within experimental error, of $\bar{\nu}$ for thermal neutron fission of U-235 ($2.416 \pm .008$).
- The approximately correct value, within experimental uncertainty, of the number of alpha particles per U-235 fission (one alpha particle in every 300-500 fissions).

For integral frequencies it is evident that f_D (the frequency of Mode D) cannot be less than one.

Two other observations were made, based on the percent yield data above:

- The ratio of the fission yield for Mode B (27.40%) and that for Mode C (22.83%) is exactly 1.20.
- The sum of the fission yields for Modes B and C is 50.23%, very close to the fission yield of Mode A (49.73%). This led to the postulate that the sum of the fission yields of Mode B and C equals the fission yield of Mode A.

Thus, the following frequency conditions were established:

- All frequency values are integral
- $f_D = 1$
- $f_B / f_C = 1.20$
- $f_B + f_C = f_A$

Figure 8 shows the $\bar{\nu}$ values calculated for five possible Σ_f values (23, 45, 67, 89, and 111). As can be noted, all frequencies except $\Sigma_f = 23$ result in $\bar{\nu}$ values within experimental error.

To select the correct Σ_f , the alpha particles per fission (α/Σ_f) have been calculated using the following simple relationship:

$$\alpha/\Sigma_f = (f_D/\Sigma_f) (\alpha/f_D)$$

Σ_f	f_D/Σ_f	α/f_D	α/Σ_f	Acceptable*
23	1/23	16/96	1/138	No
45	1/45	16/96	1/270	No
67	1/67	16/96	1/402	Yes
89	1/89	16/96	1/534	No
111	1/111	16/96	1/666	No

*Within experimental limits of error (400 ± 100).

Figure 9. Thermal Neutron Fission of U-235. Calculation of the number of alpha particles per fission for the five values of Σ_f in Figure 8.

where α/f_D has previously been shown (see Mode D) to be 16/96. Figure 9 shows the results of these calculations. Only $\Sigma_f = 67$ provides for the correct solution for both $\bar{\nu}$ and α/Σ_f . (See A) and B) above.) It is striking that the total frequency of the four fission modes should be 67, a value identical to the key mass number in the NCM.

Figure 10 shows the final NCM-generated fission yield curve (solid circles) using $\Sigma_f = 67$, as well as the experimentally deter-

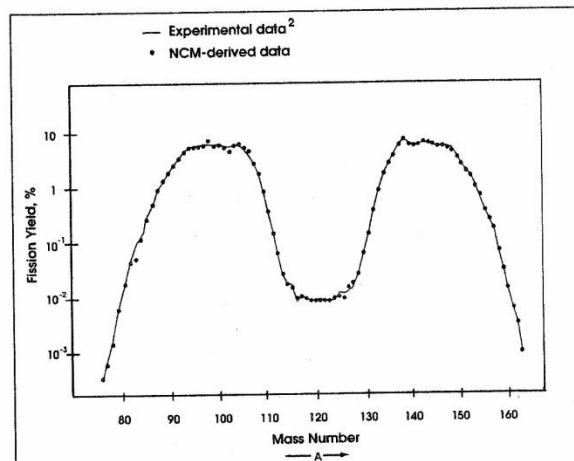


Figure 10. Fission Yields for Thermal Neutron Fission of U-235.

Fissile Nuclide	Experimental $\bar{\nu}$		NCM Fission Mode Frequencies				Σ_f	NCM $\bar{\nu}$
	Value ³	Range	A	B	C	D		
U-233	2.492 ± .008	(2.484 - 2.500)	31	11	13	12	67	2.493
U-235	2.416 ± .008	(2.408 - 2.424)	33	18	15	1	67	2.418
Pu-239	2.904 ± .008	(2.896 - 2.912)	18	24	18	7	67	2.910
Pu-241	2.947 ± .007	(2.940 - 2.954)	16	23	17	11	67	2.940

Figure 11. Thermal Neutron Fission. Variation of $\bar{\nu}$ with fissile nuclide mass number A.

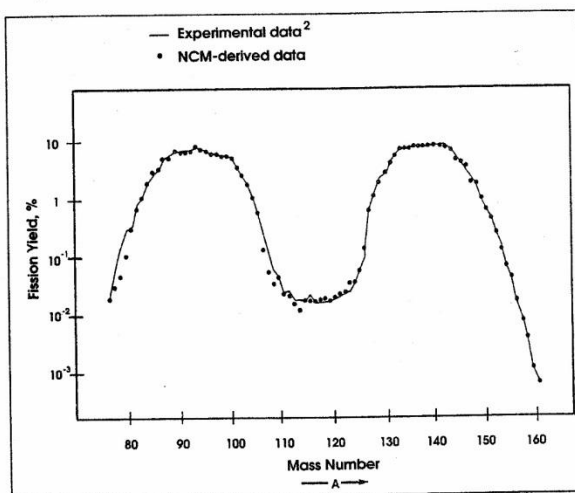


Figure 12. Fission Yields for Thermal Neutron Fission of U-233.

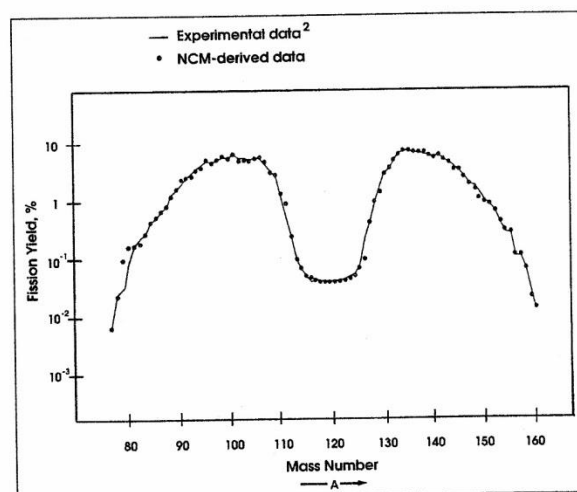


Figure 13. Fission Yields for Thermal Neutron Fission of Pu-239.

mined fission yield data (computer-trace line). As can be noted, the agreement is excellent, especially when it is recognized that experimental fission yields are, in most cases, uncertain by ± 10 -20%.

Thermal Neutron Fission of U-233, PU-239, and PU-241

Further research, utilizing the uniquely determined frequency $\Sigma_f = 67$, the four NCM fission modes, and the appropriate fission yield curves, has produced $\bar{\nu}$ values in excellent agreement with experimental values for U-233, Pu-239, and Pu-241, shown in Figure 11. Examination of mode frequencies for these fissile nuclides shows that, while Σ_f is constant, mode frequencies are shifted. The corresponding fission yield curves, also in remarkable agreement with experimental data, are shown in Figures 12, 13, and 14.

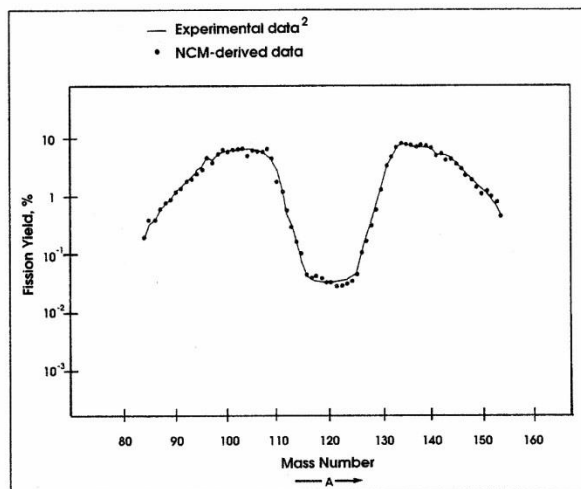


Figure 14. Fission Yields for Thermal Neutron Fission of Pu-241.

Conclusions

The NCM has been successfully utilized to derive a complete systematic model for thermal neutron fission of U-235 which:

- 1) reproduces the experimental fission yield curve;
- 2) reproduces the experimental value of $\bar{\nu}$;
- 3) accounts for neutron emission ranging from 0 to 6, and identifies the source of all prompt fission neutrons;
- 4) identifies the origins of alpha particles and tritons [the principal light charged particles (LCP)] and produces excellent agreement with the experimental ratio;
- 5) produces the approximately correct yield of alpha particles in fission;
- 6) shows the prominent influence of $N = 50$ and 82 .

The most significant conclusion from this research is that the Nucleon Cluster Model has been tested and derives, for the first time, key experimental results in thermal neutron fission, not only in U-235, but also in U-233, Pu-239, and Pu-241, never before explained. Additional papers validating the NCM are in preparation.

Acknowledgments

Dr. Frederick Forscher, a Director of NSRC, provided stimulating and creative suggestions during this research, as well as a critical review of this paper. Mr. Charles McNeill, a graphics consultant to NSRC, produced all figures in this paper, and his contributions are gratefully acknowledged.

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[Editor's Note: R.A. Brightsen was unavailable to clarify discrepancies in References 4 and 7. Our search found that these authors published separate books on nuclear fission. R. Vandenbosch is sole author of *Nuclear Fission*, which is out of print. It appears that J. Huizenga was contributor or editor for the proceedings of the International Symposium on Nuclear Fission and Heavy-Ion-Induced Reactions, which is also entitled *Nuclear Fission*.]

Appendix A. Derivation of Fission Yield Curve for U-235

Call the distribution curves for the individual modes the A-curve, the B-curve, the C-curve, and the D-curve. Since Mode A emits one neutron, the A-curve is symmetric around 117.5 (one-half of $236-1$). Similarly, the B-curve is symmetric around 117, the C-curve around 115, and the D-curve around 116.5. The total yield curve is the sum of these four curves.

The restrictions on the curves are the following: They must yield the desired total distributions for A, B, C, and D. They are defined only in the appropriate ranges (for example, the C-curve only runs from $A = 84$ to $A = 96$ and, by symmetry, from $A = 134$ to $A = 146$). It is also reasonable to require that the curves be fairly smooth, having only minor local variations.

It is easy to see that the above restrictions are fairly rigid. For example, if the percentages of C are made larger, then the percentages for A for the same mass numbers must be made smaller. Since these mass numbers form most of the peaks, there is not enough yield elsewhere to make A large enough to compensate. Since six neutrons are produced in Mode C, while only one is produced for each fission in A, this would raise the value of $\bar{\nu}$. Correspondingly, lowering the percentages for C would tend to lower $\bar{\nu}$. It follows that the values for C should be moderately large. When these principles are carried out numerically, then adjusted to get a better fit, it is seen that the total percentage for C must be approximately the 22% given. Likewise, though B has a large range, most of it lies in a region where the experimental yield is small. The part of the curve corresponding to the peaks is for yields that must be shared with A. Again, as above, the balance between the two modes is fairly rigidly determined by $\bar{\nu}$. The fact that the different curves have different centers of symmetry plays a major role in the final determination of the percentages. For example, suppose the value for B for mass 99 is raised. Then the percentage for A for mass 99 must be lowered. By symmetry, the value for B for mass 135 must be raised and the value for A for mass 136 must be lowered. This latter change can be offset by raising the value of C for mass 136, hence by symmetry also raising the value for C for mass 94. The value of A for mass 94 can now be lowered, etc. So, a change in one value results in a change in many values. This introduces a lot of rigidity into the system, and causes the final distributions of percentages to be determined fairly accurately.

One feature of putting together four curves with different centers of symmetries is that the sum of the four curves will not be smooth, and will have local variations such as those occurring at the peaks. These irregularities have been observed experimentally and are not explained by other models.

The overall conclusion is that it is possible to have four modes as

described, each with its own distribution curve, and still be consistent with the experimental yield curve. The rigidity of the situation, as described above, indicates that this consistency would probably fall if variations were to be introduced in the individual modes.

About the Author

As a scientist and business executive, Ronald A. Brightsen has been actively involved for many years in military and civilian uses of nuclear physics. During World War II he worked as an



analytical chemist on the first atomic weapons project at Oak Ridge. He also participated in the 1948 atomic weapons test in the South Pacific, and later helped establish the project that detected the first Russian atomic weapons test in 1949. As a senior scientist at the Atomic Power Division of Westinghouse, he headed radiochemical experiments in conjunction with development of the first nuclear-powered submarine and the first U.S. civilian nuclear

power plant. In 1954, Brightsen established the Nuclear Science and Engineering Corporation, the nation's first commercial enterprise aimed at developing the industrial application and production of radioactive isotopes. In more recent years, he held several senior positions at the U.S. Nuclear Regulatory Commission. In 1985 he created Nuclear Science Research Corporation (later to become Clustron Sciences Corporation), in order to further develop his personal research on nuclear structure; this research ultimately led to the creation of the Nucleon Cluster Model. In 1985, he retired from the NRC to devote full-time attention to the development of the science and potential practical applications of the Nucleon Cluster Model.

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